Restoration of the Salton Sea

Volume 1: Evaluation of the Alternatives

Appendix 1O: Scientific Note for the Development of DO Demands and a Concept-Level Oxygenation Diffuser System for South Lake of the Salton Sea

SCIENTIFIC NOTE FOR THE DEVELOPMENT OF DO DEMANDS AND A CONCEPT-LEVEL OXYGENATION DIFFUSER SYSTEM FOR SOUTH LAKE OF THE SALTON SEA

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Objectives

Determine the DO demands in the lower water layers of the proposed South Lake of the Salton Sea using available data, and estimate the size of an oxygenation system that would be needed to prevent fish kills when the lake mixes.

Current Conditions

The Salton Sea normally experiences significant mixing with periodic, short-term strong stratification periods. During these brief short periods of little mixing, DO demands far exceed the available DO content of the water and anoxic products such as sulfides and ammonia occur. When mixing occurs between the surface layer that has high DO and the bottom layer that contains the anoxic products, the anoxic products gradually (over hours and days) oxidize or escape to the atmosphere and become "harmless." However, before they can oxidize or escape they can occur at the surface of the lake in concentrations that might exceed toxic limits for fish and cause fish kills as well as consume DO in the mixed water column to the extent that DO is low enough to result in fish kills.

The DO demands reported by Horn and Holdren (2005) are the highest ever observed by the author who has experience with over 110 large reservoirs. Chl a levels are high indicating that significant levels of organic matter are produced by algae in the system. In 2005, mean Chl a levels for the period April through September were 165 µg/L which can indicate algal mass levels of about 10 to

20 mg/L using the normal range of Chl a content for algae; maximum Chl a levels occurred in June and were 265 μg/L which can indicate algal mass levels of about 15 to 33 mg/L. These algal masses represent a continual production of organic mass that grows, dies, and settles in the water column, continually supplying organic matter to the lower layers of the lake as well as to the sediments.

Values of TSS are another indication of algal mass and associated organic matter. The mean TSS during the growing season was 40 mg/L for the available data in 2004-2005—this value is consistent with a median value of 34 mg/L for the surface layers and 24 mg/L for the bottom layers in 1999.

Another form of organic matter is dissolved and is measured by DOC analytical procedures. The total DOC was about 44 mg/L in the Salton Sea in 1999 and 47 mg/L based on two sampling dates in 2006. Much of this DOC is probably refractory and does not readily decompose within days and weeks, but more like over months and years. However, even if a small portion (i.e., 20-30%) of DOC was labile, the DO demands would be significant.

As this organic matter decomposes, DO is consumed to the extent it is available and then anoxic products start forming and accumulate in the bottom layers until they are oxidized or mixed with the upper layers of the lake. The accumulation of anoxic products creates additional DO demand that is exerted when the lake mixes or is oxygenated.

DO Demands and Concept Diffuser System for South Lake

Schladow (2005) showed that the South Lake would be stratified for several months during the “summer months” with a thermocline occurring at the 3- to 4-m depth. At these depths the volume of the lower water layers would be 2 to 1.6 million ac-ft, respectively. This stratification would cause depletion of DO in the bottom layers of the lake and higher concentrations of anoxic products than currently observed.

In systems like the proposed South Lake, experience has shown that the best approach for using oxygen diffuser systems is to add oxygen through out the low DO period so that the lower layers of the lake are oxygenated essentially all the time. This approach attempts to avoid the accumulation of anoxic products and to maintain a reserve of oxygen mass in the lower layers to accommodate DO demands for oxidizing the organic matter that is continually produced through out the algal growing season.

To design oxygenation systems for lakes like the Salton Sea, ecosystem models should be used to simulate the DO demands as well as the performance of various sizes and configurations of oxygenation systems. Calibration of the model assists greatly in developing realistic DO demands considering that the model accounts for all the dominant factors that affect DO demands. Following calibration, the model is used in an iterative process until an acceptable level of water quality is produced using an acceptable size of diffuser system. Considering the complex dynamics of lakes like the Salton Sea, these models are run with hourly time steps. Loginetics, Inc (Gary Hauser with assistance from Ruane and Mobley) has modified a CE-QUAL-W2 model that includes typical DO demands as well as an oxygenation diffuser.

The design for this oxygenation system is considered to be at the “concept” level, and the size and cost estimate are considered to be within about ± 50%. This level of design is done without the benefit of a model, but the approach is consistent with processes within the model. The main factors accounted for in this concept design include DO demands attributed to dissolved and particulate organic matter in the water column (including the production of ammonia as the organic matter is oxidized) and SOD.

Based on experience at other projects, LPOM (labile particulate organic matter) was estimated to be 72% of the TSS. This seemed appropriate for the Salton Sea since it has high levels of Chl a. Since TSS in the bottom layers was 25 mg/L, the LPOM was estimated to be 18 mg/L.

To estimate the distribution of organic matter between refractory and labile components (i.e., RDOM and LDOM, respectively), the following procedure was developed.

To estimate refractory organic carbon (TOC_R) and labile organic carbon (TOC_L), these two equations were used:

$$TOC = TOC_L + TOC_R$$

$$TON = TON_L + TON_R$$

where TON_L is the nitrogen content of labile organic matter, and TON_R is the nitrogen content of refractory organic matter.

Solving for these two equations:

$$TOC = TOC_L + TOC_R$$

$$(TON/TOC)*TOC = (TON_L/TOC_L)*TOC_L + (TON_R/TOC_R)*TOC_R$$

where:

TON/TOC can be calculated using Duke data

TON_L/TOC_L = 1/5.6 (i.e., N/C = 8/45 or 7.2/40 from Wetzel, 2001; Bowie et al, 1985; Sterner and Elser, 2002)

TON_R/TOC_R = 1/50 (Wetzel 2001) (also consistent with others)

Solving for TOC_L,

$$TOC_L = 6.31*(TON - 0.02*TOC)$$

To check sensitivity for application to the Salton Sea, $TON_R/TOC_R = 2/50$ was also considered.

As organic matter is oxidized, ammonia is a product that exerts additional DO demand, usually about 23% of the overall DO demand attributed to the oxidation of organic matter (Chapra, 1997). In the lower water layers of the Salton Sea the estimated ammonia level was 3 mg/L which is consistent with the maximum levels that were observed in 1999. It is reasonable to expect that the estimated ammonia levels formed by oxidation of the organic matter would be near the maximum levels observed in the field since the latter levels reflect the effects of nitrification that reduces ammonia levels.

SOD values reported by Amrhein and Anderson, 2005, were used since these data were the only available. To test sensitivity, these values were doubled considering others have reported that SOD can double when aeration/oxygenation systems are employed. In addition, considering the comments expressed about these data by the authors, a national data base compiled by EPA was reviewed and values double those measured on the Salton Sea were considered to be reasonable to use for sensitivity.

It should also be mentioned that a range of biological oxidation rates were also considered: for LDOM, 0.12 to 0.15 day^{-1}; for LPOM, 0.05 to 0.08 day^{-1}; and RDOM, 0.001 to 0.005 day^{-1}. Considering that organic matter is essentially continually produced and settles to the lower layers of the lake on a daily basis, it was assumed that the DO demand rate was first-order and that the rate was set at the day 1 rate every day during the period of oxygenation.

The oxygen transfer efficiency for the diffuser system was assumed to be 85%; oxygen costs were assumed to be $110/ton; the system was assumed to operate 120 days/yr; and a factor of safety 1.25 was used in developing the diffuser design, oxygen costs, and cost estimate.

The results are presented in the following table.

Table 1.—Summary of Estimated DO demands and Concept Design of an Oxygenation Diffuser System for South Lake of the Salton Sea

Diss. Labile Organic matter, mg/L	Ultimate Diss. labile DO demand, mg/L	Daily DO demand--Diss. labile OM, mg/l/day	Part. Labile Organic matter, mg/L	Ultimate Part. labile DO demand, mg/L	Daily DO demand--Part. labile OM, mg/l/day	Refractory Organic matter, mg/L	Ultimate refractory DO demand, mg/L	Daily DO demand--refractory OM, mg/l/day	Ammonia, mg/L	NBOD, mg/L	Daily DO demand--NHx, mg/l/day	SOD, mg/l/day	Total daily DO demand in hypolimnion of water column, mg/l/day
17.6	24.6	2.8	18	25.2	1.2	79.5	111.2	0.55	3	13.0	1.5	0.8	**6.9**
29	40.6	4.4	18	25.2	1.9	69	96.6	0.1	3	13.0	1.5	1.6	**9.5**

Total daily DO demand in hypolimnion of water column, mg/L	**Total volume of hypolimnion--South Lake, ac-ft**	**tons/day of DO demand**	**tons/day of Oxygen demand considering OTE and safety factor**	**Length of porous hose diffuser required, miles**	**Estimated Cost of porous hose diffuser line, millions**	**Estimated Annual Cost of Oxygen, millions/yr**	**Estimated Present Worth for Cost of Oxygen, billions**	**Estimated Present Worth of Capital and O&M costs, billions**	
6.9	**1,600,000**	**14,988**	**22,042**	**700**	**$150**	**$291**	**$2.9**	**$3.1**	**~ low estimate**
6.9	**2,000,000**	**18,736**	**27,552**	**876**	**$188**	**$364**	**$3.6**	**$3.8**	**~ low estimate**
9.5	**1,600,000**	**20,636**	**30,348**	**964**	**$207**	**$401**	**$4.0**	**$4.2**	**~ high estimate**
9.5	**2,000,000**	**25,795**	**37,934**	**1205**	**$258**	**$501**	**$5.0**	**$5.3**	**~ high estimate**